The Soil Water Characteristic curve - relevance of time to hydrologic equilibrium

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Keywords: Soil water characteristic curve; lag time; water framework directive.

Abstract

The European Union (EU) Water Framework Directive (EU-WFD; EC, 2000) requires that all surface and groundwater bodies achieve ‘good status’ within set reporting deadlines. Parameters derived from the soil water characteristic curve (SWCC) serve as inputs to numerical models (Mualem, 1976; Van Genuchten, 1980), which are crucial in predicting solute transport timescales in the field (Vero et al., 2016). Strictly, the occurrence of true ‘hydrologic equilibrium’ (Eₜ) at each suction step is required in the development of the SWCC. To date, generic equilibrium times have been used in the development of SWCCs, and do not consider the potential impacts of soil texture and bulk density on the attainment of Eₜ. This study addresses this knowledge gap by examining the impact of equilibrium times of 12, 24, 48 and 72 hours on the development of SWCCs across soils of varying texture and density.

1. Introduction

The soil water characteristic curve (SWCC) defines the relationship between the volumetric water content (θ), or degree of saturation (Sₙ), of a soil and its suction/matrix potential (Ψ). Research to date has examined the effect of soil physical parameters, such as bulk density (ρₐ), texture, and additives to the soil on the form of the SWCC (Tinjum et al., 1998; Gallage and Uchimura, 2010; Fu et al., 2011; Malaya and Sreedeed, 2012). However, the appropriate SWCC for input to numerical models is that for which the volumetric water content has been allowed to equilibrate at each suction level, known as true hydrologic equilibrium (Eₜ) (Vero et al., 2016). In practice, hydrologic equilibrium represents the point at which the residual water within soil has no further network of pores through which it can drain. Determination of true hydrologic equilibrium, and its dependence on soil physical parameters, has received scant attention in the literature.

Examination of the literature has revealed a large variation in the testing times used in SWCC construction, derived for different methodologies, suction ranges and soil physical parameters. There is no evidence to suggest that these are systematically-derived equilibrium SWCCs.

Inaccuracies in determining equilibrium SWCCs may lead to under- or over- prediction of the ‘lag times’ associated with adoption of better agricultural practices.

Inaccurate estimation of lag times may potentially lead to penalties for surface and groundwater bodies not achieving ‘good’ status within the reporting deadlines of the Water Framework Directive (EU-WFD; EC, 2000) (Vero et al., 2016).

Therefore, the aim of this research is to investigate, using a centrifuge: (1) the effect of soil texture and bulk density on soil drainage and (2) their effects on the time required to achieve a state close to true hydrologic equilibrium.

2. Methodology

The three soils used in this study were, sandy-loam (samples 1 and 2) and clay-loam (sample 3), which had bulk densities (upon saturation in the laboratory) between 1.12 and 1.67 g/cm³ (Table 1).

Table 1 – Sample IDs, textures and average bulk densities (BDs)

<table>
<thead>
<tr>
<th>ID</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Sand (%)</th>
<th>12hr</th>
<th>24hr</th>
<th>48hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.9</td>
<td>28.6</td>
<td>58.6</td>
<td>1.46</td>
<td>1.32</td>
<td>1.28</td>
</tr>
<tr>
<td>2</td>
<td>4.9</td>
<td>39.5</td>
<td>55.6</td>
<td>1.63</td>
<td>1.64</td>
<td>1.67</td>
</tr>
<tr>
<td>3</td>
<td>34.7</td>
<td>20.4</td>
<td>44.9</td>
<td>1.14</td>
<td>1.12</td>
<td>1.12</td>
</tr>
</tbody>
</table>

The SWCCs for each soil were developed using the centrifuge method (Smagin 2012). In this method, soil cores (n = 3 per sample), with a diameter of 23 mm and a length of 70 mm, were placed in a temperature-controlled (10°C) centrifuge (Sigma 4-16KS, Osterode am Harz, Germany). The centrifuge was then operated at various centrifugal forces, so that target soil suctions were attained at each time interval. The Gardner equation (Gardner 1937) was used to calculate the suction on the soil:

\[ \phi = \left( \frac{w^2 \rho_l (r_2^2 - r_1^2)}{2} \right) \times 10^{-3} \]

(Eqn 1)

where \( \phi \) is the matric suction (kPa), \( \omega \) is the angular velocity (radians per second (s⁻¹)), \( \rho_l \) the density of the liquid (water-kg/m³), \( r_2 \) (m) is the distance from the centre of rotation (COR) to the free water surface, and \( r_1 \) (m) is the distance from the COR to the midpoint of the soil sample. The equation is manipulated so that the correct centrifugation velocity (\( \omega \)) is chosen to provide the desired suction (\( \phi \)).

The nominal suction steps used were -5, -10, -35, -80, -100, -200, -500 and -1000 kPa. These suction steps were...
chosen to facilitate a wide range of soil textures. The SWCCs were developed by back-calculating the volumetric water contents after oven drying the soil samples for 24 hr at 105°C.

3. Results and Discussion

The 48 hour SWCCs (assumed to be equalized, verified later) are used to consider the effects of bulk density and texture on drainage (Figure 1). Sample 2 has the lowest effective saturation values, followed by samples 1 and 3. Considered in conjunction with Table 1, the data suggest that both bulk density and texture may have an influence on drainage characteristics, but further systematic investigation is warranted to establish the relative effects of each.

Average SWCCs for each soil type and for the three suction-steps are shown (Figures 2 and 3). Based on these plots, a hydrologic equilibrium time of 24 hours seems appropriate for samples 1 and 3. In the case of sample 2, it is not as obvious as to which suction step duration is adequate. Pressure step durations of over 100 hours have been used for sandy loams (Dexter et al., 2012). Appropriate statistical analyses are required to investigate differences between the data points for these centrifugation times.

4. Conclusion

Further work is required to establish the degree to which bulk density and texture effect soil drainage. Statistical analysis techniques should be used to compare effective saturation values between the different suction step times. This will help to find where the hydrologic equilibrium times converge for each sample.

Acknowledgements

The first author acknowledges the scholarship received from the College of Engineering and Informatics at NUI Galway.

References
